COMPARING WAVE POWER FROM A NORTHERN AND A SOUTHERN SITE

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SUMMARY AND INTRODUCTION

Instantaneous wave power at a single site varies considerably with time. Combining the power outputs from two distant sites could be a way of reducing the variation in instantaneous power output.

Wave data from Boyle, about 100 miles south of Ireland, and for Fitzroy, about 50 miles west of Shetland, were examined with a view to discovering what advantages might be gained by mixing power outputs from these two sites.

Two sizes of duck were chosen for each site and power exceedance curves were plotted for these, as well as for the available power (Figs. 4-9). To examine the effect of mixing power outputs from the two sites, the powers were scaled so that the mean over the season being considered was the same for each site. This is equivalent to considering power stations of the same average output at both Boyle and Fitzroy. Scaled powers were then mixed in the ratio 1:1 and power exceedance curves were plotted (see Figs. 10-18).

Over the whole year 7503/7602 the effect of using the mixed output is to increase the percentage of the time a power level is exceeded by about 5-7% for powers in the range 20-70% of average (see Figs. 12, 15 & 18).

If, however, the mixture was arranged with the aim of improving a particular season, then the improvement over that season might be greater. For example, for summer 7506/8 with 10 or 15 m ducks, the improvement is about 7-10% over the same range of powers (see Figs. 10, 13 & 16).

DATA USED

Waverider Buoy (WB) and Shipborne Waverecorder (SWR) data are available for both sites for a number of years. It is believed that the WB data is more accurate and this has been used where possible. Where WB data was not available but SWR was, this was used to estimate the WB readings. This gave a fairly good set of data, and the year 7503/7602 was selected as the one for which most data was available. The worst month was 7601 with about 59% of possible data actually available, but most months had available 70-85% of possible data.

WB readings were estimated from SWR readings as follows:

For each instrument, the measurements recorded are "Zero Crossing Period", TZ and "Significant Wave Height", HS.

Taking times for which there was data for both instruments, plots were made of HS(WB) against HS(SWR) and TZ(WB) against TZ(SWR). This was done for each site. Results are shown in Figures 1-2.

A straight line was fitted to each data set using the method of "Least Squares". Then a straight line through the origin was fitted to each data set by the same method. As this second line gave only slightly different results from the first one, it was preferred for simplicity.

The fitted lines were:

Boyle:	HS(WB) = 0.918 HS(SWR)
	TZ(WB) = 0.973 TZ(SWR)
Fitzroy	HS(WB) = 0.925 HS(SWR)
	TZ(WB) = 0.992 TZ(SWR)

and these were used to estimate the WB readings from the SWR ones.

CHOICE OF DUCK SIZE

For any particular torque limit on a duck there is a "saturated" power limit of approximately 100 kW/m per MNm/m of torque limit, above which the additional returns for increasing the power limit are not worthwhile (see EWPP Fourth Year Report, page 8.1).

The average power output over the year 7503/7602, as a function of torque limit, assuming a saturated power limit as above, was plotted for 10, 12 and 15 m ducks, for both Boyle and Fitzroy (see Fig. 3). From this graph two reasonable duck/torque limit combinations were chosen for each of

Boyle and Fitzroy. Those chosen were:

	duck	torque limit	power limit
	m	MNm/m	kW/m
Boyle	10	0.30	30
	15	1.00	100
Fitzroy	10	0.59	50
	15	1.00	100

(Note: from Figures 8 and 17 it might appear that the 50 kW/m power limit for the 10 m duck at Fitzroy was inadequate. In fact, doubling the power limit to 100 kW/m increases the winter average output by only about 10%, and the whole year average by 7.2%.)

COMPARING THE POWER AT THE TWO SITES

If we consider a whole year there will be a correlation between power levels at the two sites. This is due to mean power levels in winter being higher than those in summer.

However, if we consider a period of time during which the mean power level remains approximately constant at each site (e.g. the summer months or the winter months) then the correlation between power levels at the two sites for this period may be less.

Data were collected from 7312 to 7605. We considered summer months (June, July, August) and winter months (December, January, February).

For each data set the correlation coefficient between the power levels at Boyle and Fitzroy was calculated, and in each case it was approximately 0.2. This is probably negligible. For example, the correlation coefficient between power levels at Boyle and those at Fitzroy some weeks later quite often produced similar values, when no 'true' correlation could be expected.

Statistical tests used to examine whether power levels, within a fixed season, at the two sites are independent are complicated by the fact that power outputs at one site are correlated with those at the same site a short time later, and no firm conclusion was reached.

For two statistically independent sites with different mean powers but the same proportional variation, it can be shown that to minimise the variation over a period of time, power outputs at the two sites should be mixed in inverse proportion to their means over that period of time.

Although the assumption of independence is unlikely to hold, it serves as a reasonable first approximation to reality and gives a criterion for getting the ratio in which to mix the powers from the two sites. So to examine the effect of mixing outputs from both sites, the power outputs for a particular period were scaled so that their means were 100 units and these 'scaled powers' were mixed in the ratio 1:1. The units here are arbitrary units of power, but it may be helpful to think of them as MW. Thus, for example, if we had duck strings at the two sites designed to give an average output of 100 MW over the summer, then (based on 7506/8 data), using 10 m ducks, the length of duck string at Boyle would be 16.1 km and the length at Fitzroy would be 10.2 km. For the same average output over winter the lengths would be 7.8 km and 2.7 km respectively.

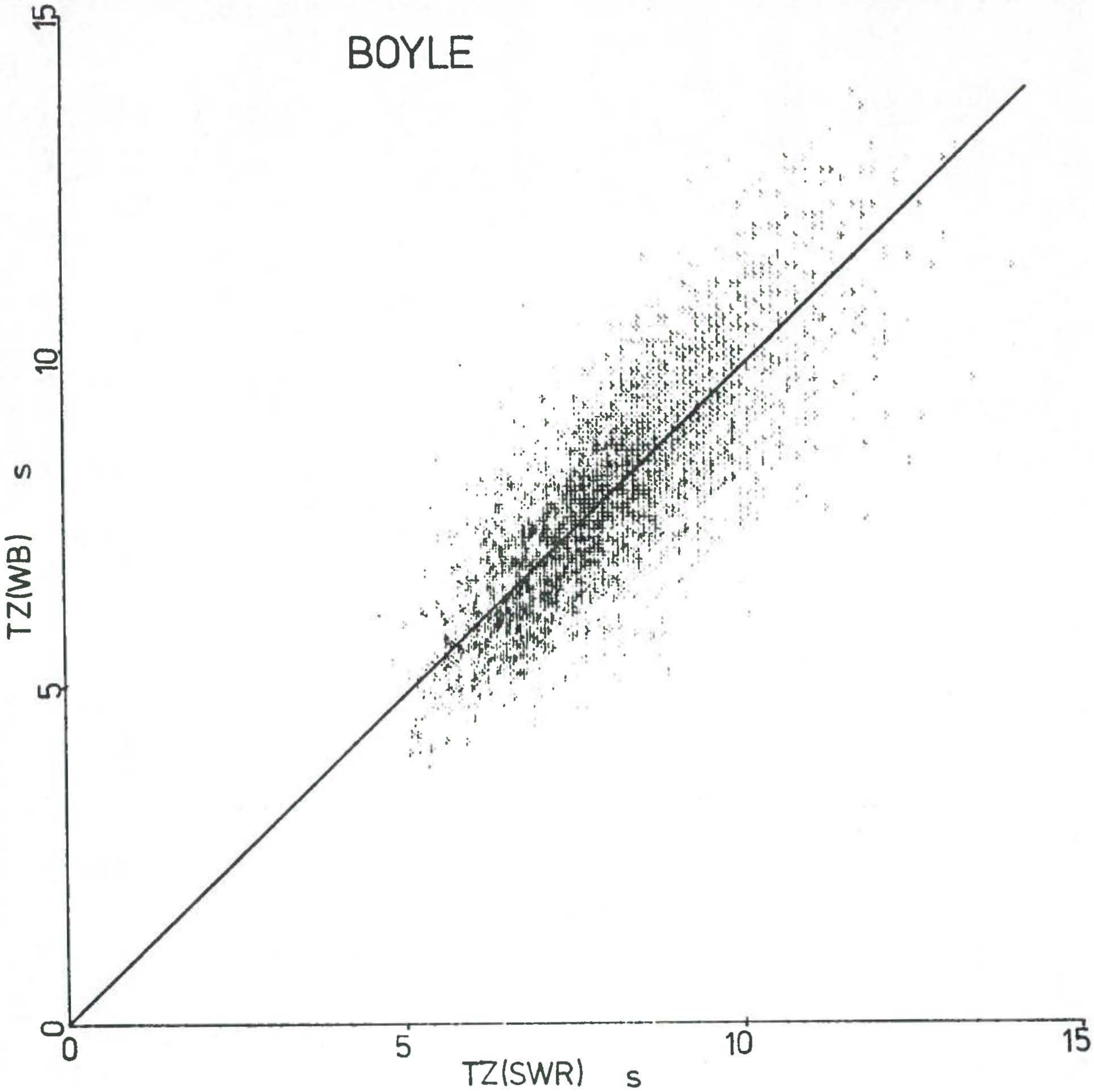
Exceedance curves were then plotted for summer, winter and the whole year 7503/7602 (see Figs. 10-18). These show that the effect of mixing powers from the two sites is roughly the same for the 15 m and 10 m ducks, and also for the available powers. These effects are:

(a) For summer: to increase the percentage of time the power is exceeded by 7-10% for powers in the range 20-70 units (% of average) and to reduce the percentage of time the power is exceeded by about 4% for powers above 140 units.

(b) For winter: to increase the percentage of time the power is exceeded by about 5% for powers in the range 10-30 units, when compared with the Fitzroy exceedance curve. Over the winter period the scaled Boyle and Fitzroy power exceedance curves are not as similar as the summer and whole year ones are. Their shape indicates that over the winter Boyle tends to have more relatively high power and relatively low power waves than Fitzroy, i.e. the power level during the winter is more variable at Boyle than at Fitzroy.

(c) For the whole year: to increase the percentage of time the power is exceeded by 5-7% for powers in the range 20-90 units and to reduce the percentage of time the power is exceeded by 2-5% for powers in the range 160-250 units.

(Note that in calculating all averages and exceedance curves each month has been given equal weight so that the averages and exceedance curves do not claim to be long term predictions, which might require different weights to be used).



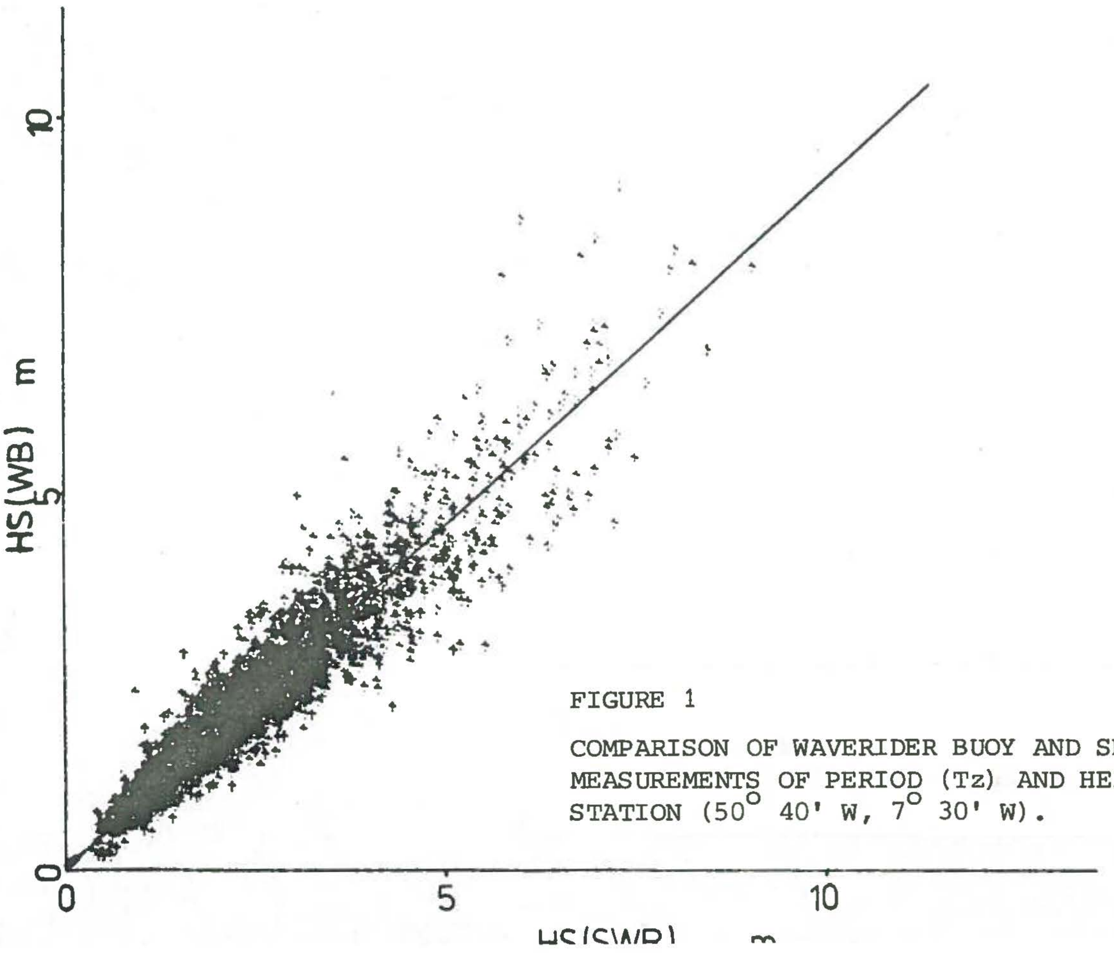


FIGURE 1

COMPARISON OF WAVERIDER BUOY AND SHIPBORNE WAVERECORDER MEASUREMENTS OF PERIOD (Tz) AND HEIGHT (Hs) AT BOYLE STATION (50° 40' W, 7° 30' W).

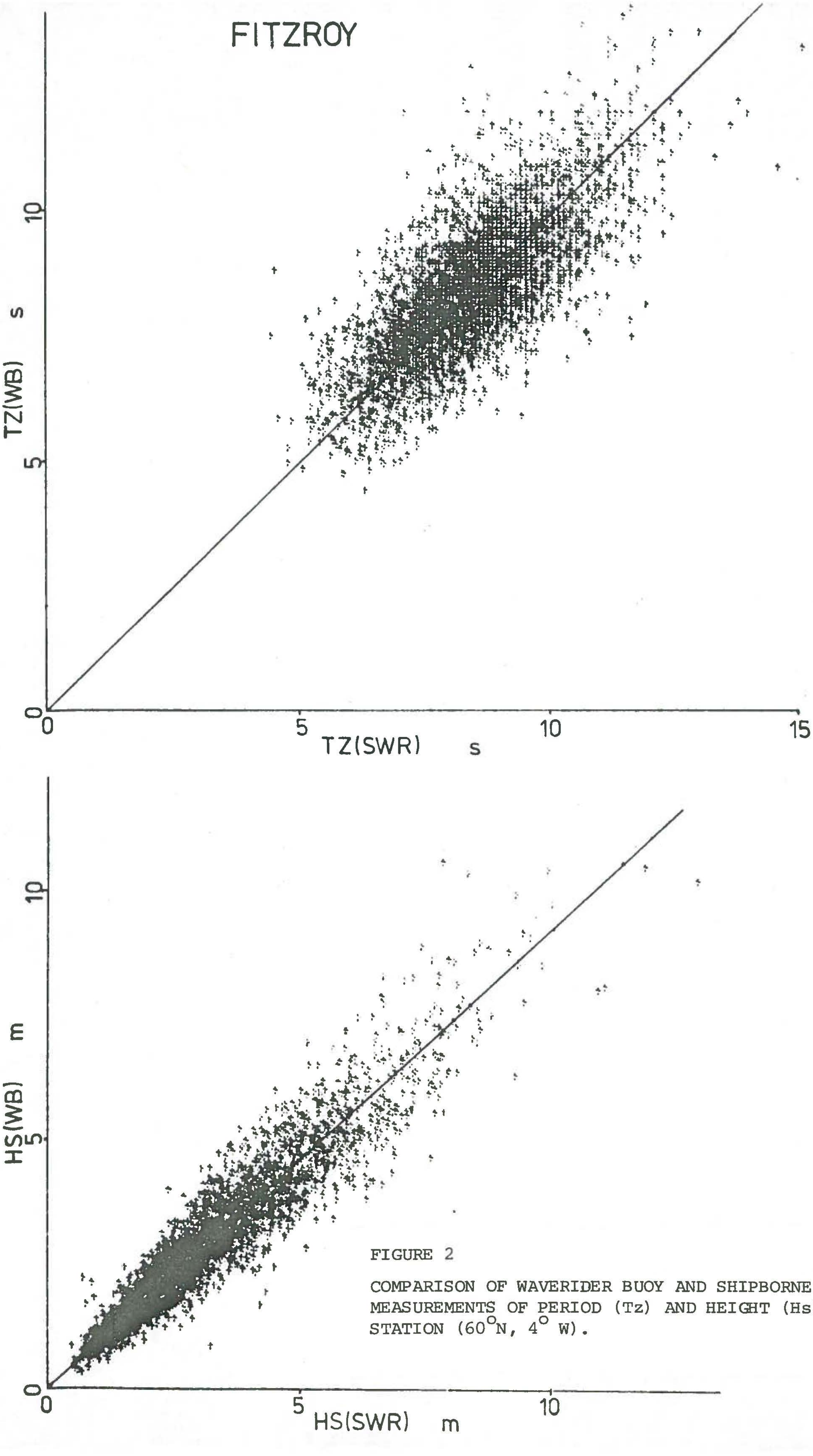


FIGURE 2

COMPARISON OF WAVERIDER BUOY AND SHIPBORNE WAVERECORDER MEASUREMENTS OF PERIOD (Tz) AND HEIGHT (Hs) AT FITZROY STATION (60°N, 4° W).

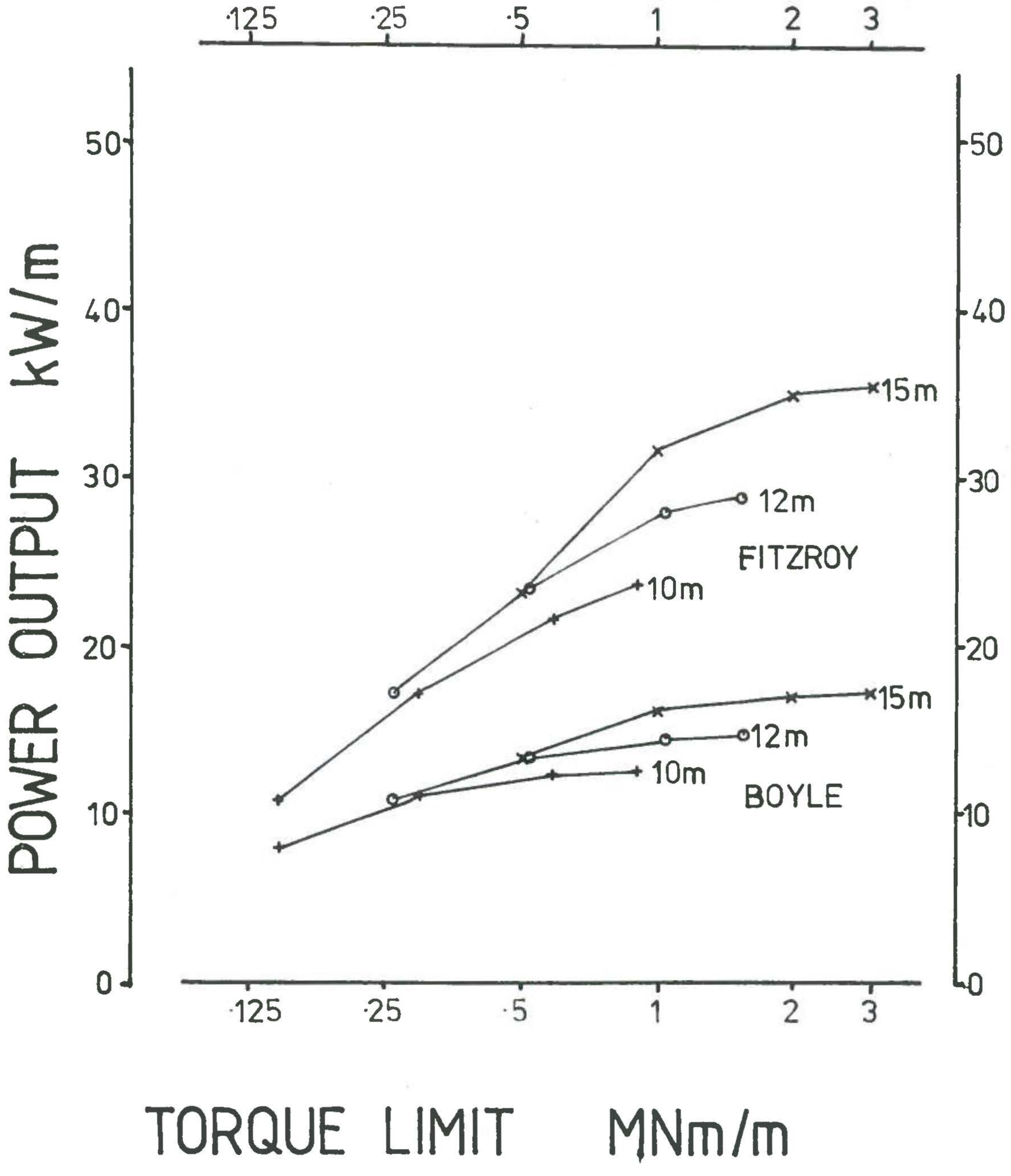


FIGURE 3

PREDICTED AVERAGE POWER OUTPUTS FOR DUCKS OF DIAMETERS 10-15 m AT FITZROY AND BOYLE STATIONS PLOTTED AS A FUNCTION OF THE TORQUE LIMIT OF THEIR POWER TAKE-OFF MACHINERY. DATA ARE FOR THE YEAR Mar 1975 - Feb 1976.

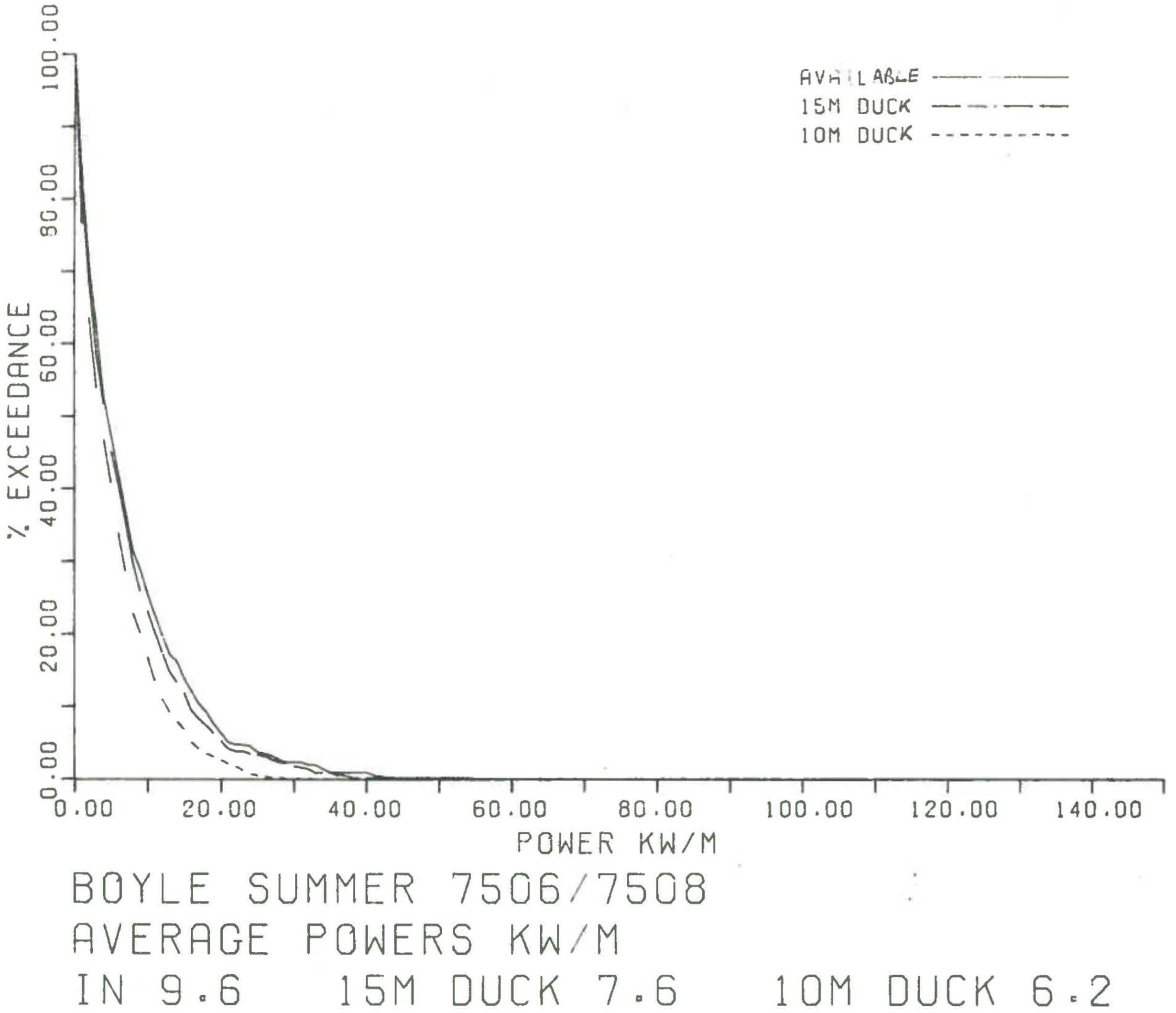


FIGURE 4

DISTRIBUTION OF POWER AVAILABLE AND PREDICTED POWER OUTPUT FOR TWO SIZES OF DUCK FOR BOYLE STATION, SUMMER 1975
15 m DUCK HAS 1 MNm/m TORQUE LIMIT
10 m DUCK HAS .30 MNm/m TORQUE LIMIT

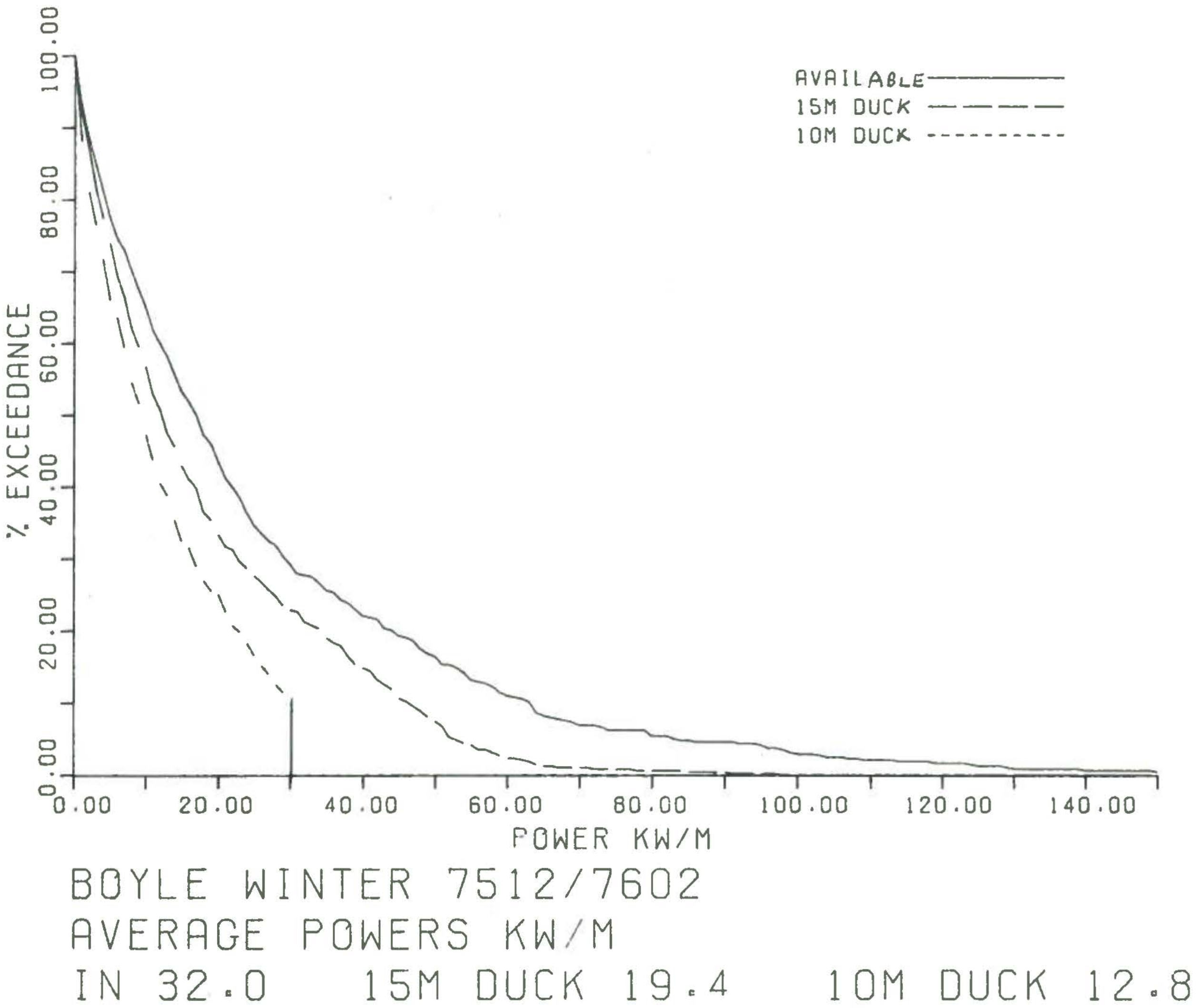
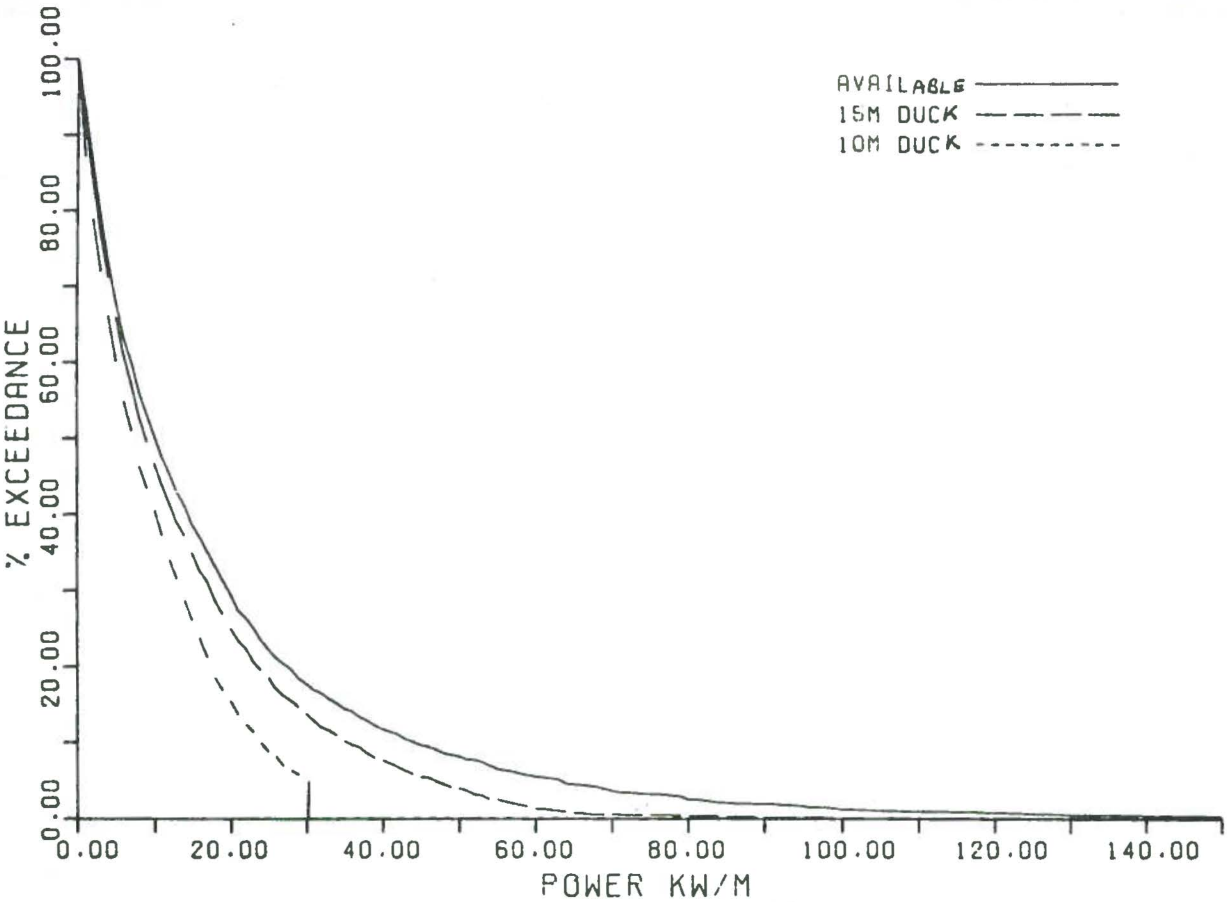


FIGURE 5

DISTRIBUTION OF POWER AVAILABLE AND PREDICTED POWER OUTPUT FOR TWO SIZES OF DUCK AT BOYLE STATION, WINTER 1975/76
15 m DUCK HAS 1 MNm/m TORQUE LIMIT
10 m DUCK HAS .30 MNm/m TORQUE LIMIT



BOYLE WHOLE YEAR 7503/7602
AVERAGE POWERS KW/M
IN 22.3   15M DUCK 15.2   10M DUCK 10.8

FIGURE 6

DISTRIBUTION OF POWER AVAILABLE AND PREDICTED POWER OUTPUT FOR TWO SIZES OF DUCK AT BOYLE STATION, WHOLE YEAR 1975/76
15 m DUCK HAS 1 MNm/m TORQUE LIMIT
10 m DUCK HAS .30 MNm/m TORQUE LIMIT

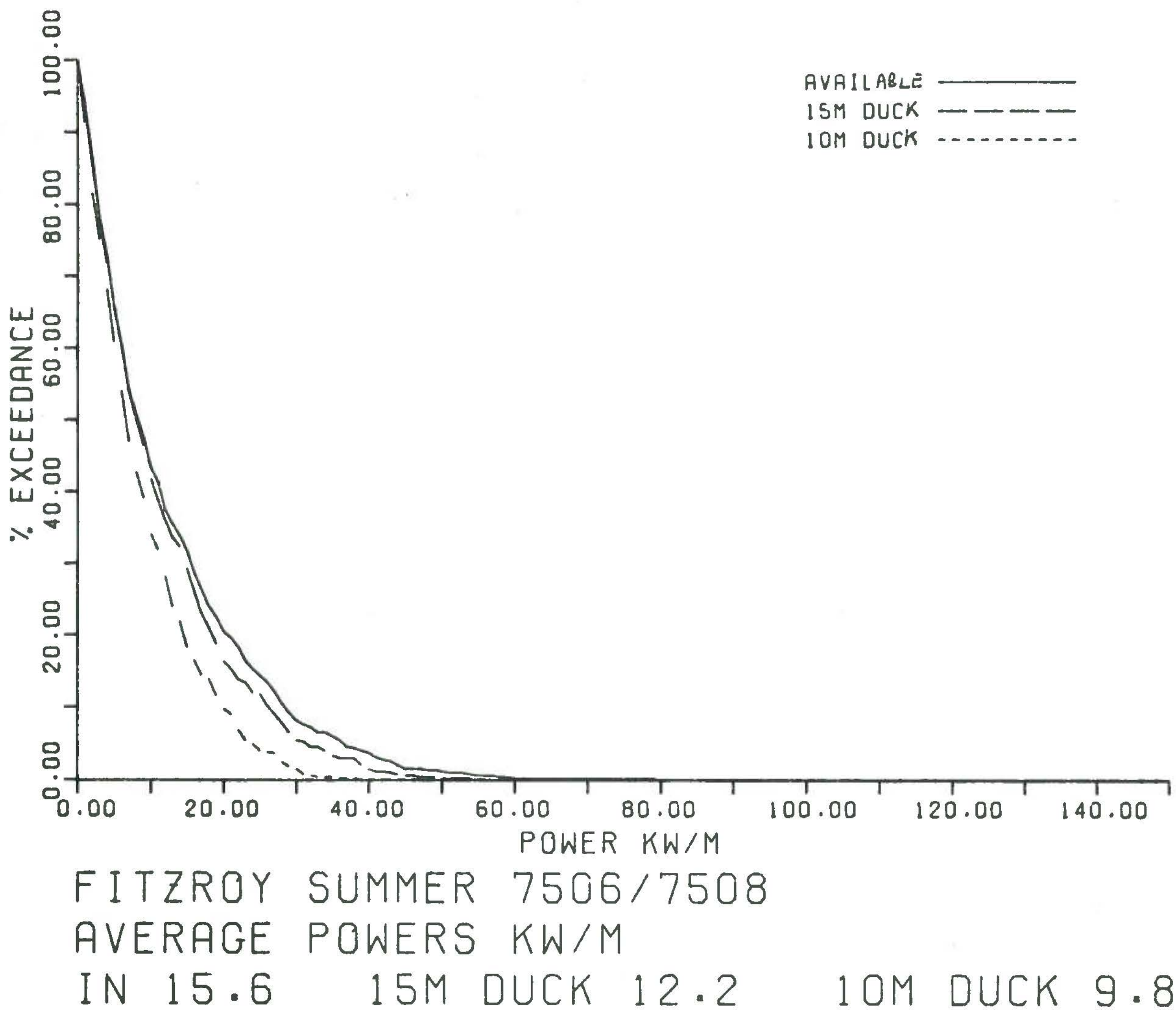


FIGURE 7

DISTRIBUTION OF POWER AVAILABLE AND PREDICTED POWER OUTPUT FOR TWO SIZES OF DUCK AT FITZROY STATION, SUMMER 1975
15 m DUCK HAS 1 MNm/m TORQUE LIMIT
10 m DUCK HAS .59 MNm/m TORQUE LIMIT

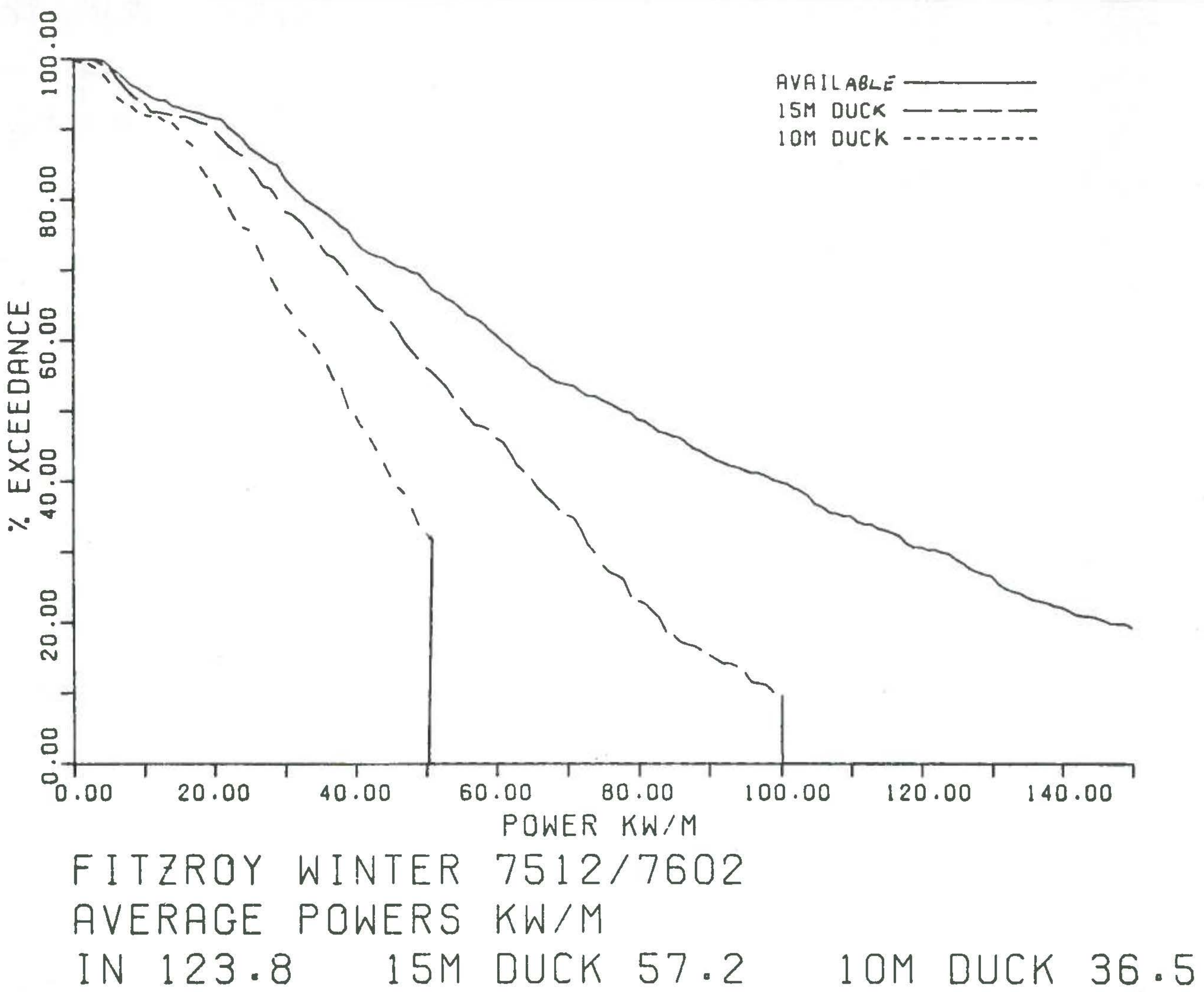


FIGURE 8

DISTRIBUTION OF POWER AVAILABLE AND PREDICTED POWER OUTPUT FOR TWO SIZES OF DUCK AT FITZROY STATION, WINTER 1975/76
15 m DUCK HAS 1 MNm/m TORQUE LIMIT
10 m DUCK HAS .59 MNm/m TORQUE LIMIT

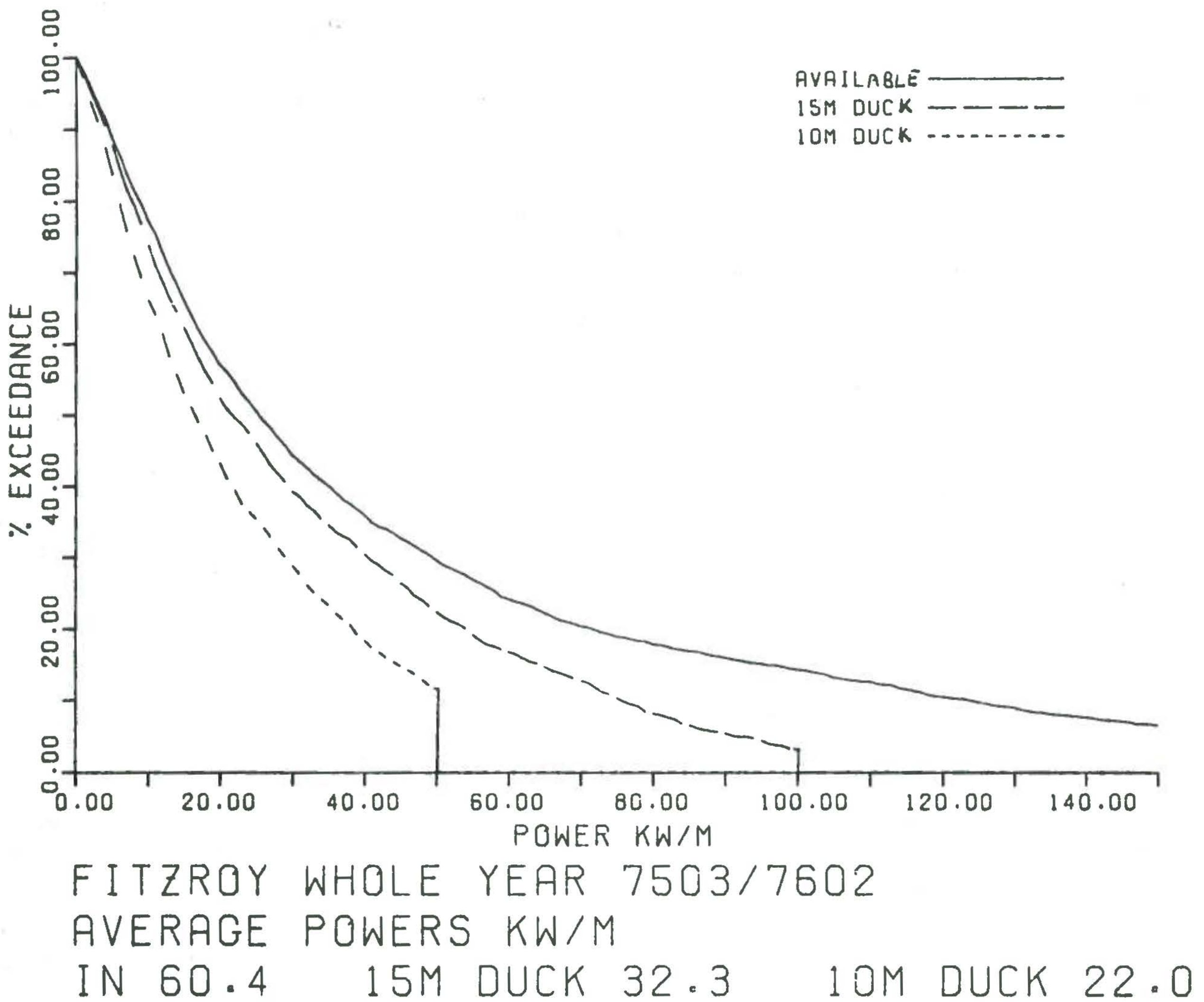


FIGURE 9

DISTRIBUTION OF POWER AVAILABLE AND PREDICTED POWER OUTPUT FOR TWO SIZES OF DUCK FOR FITZROY STATION, WHOLE YEAR 1975/76
15 m DUCK HAS 1 MNm/m TORQUE LIMIT
10 m DUCK HAS .59 MNm/m TORQUE LIMIT

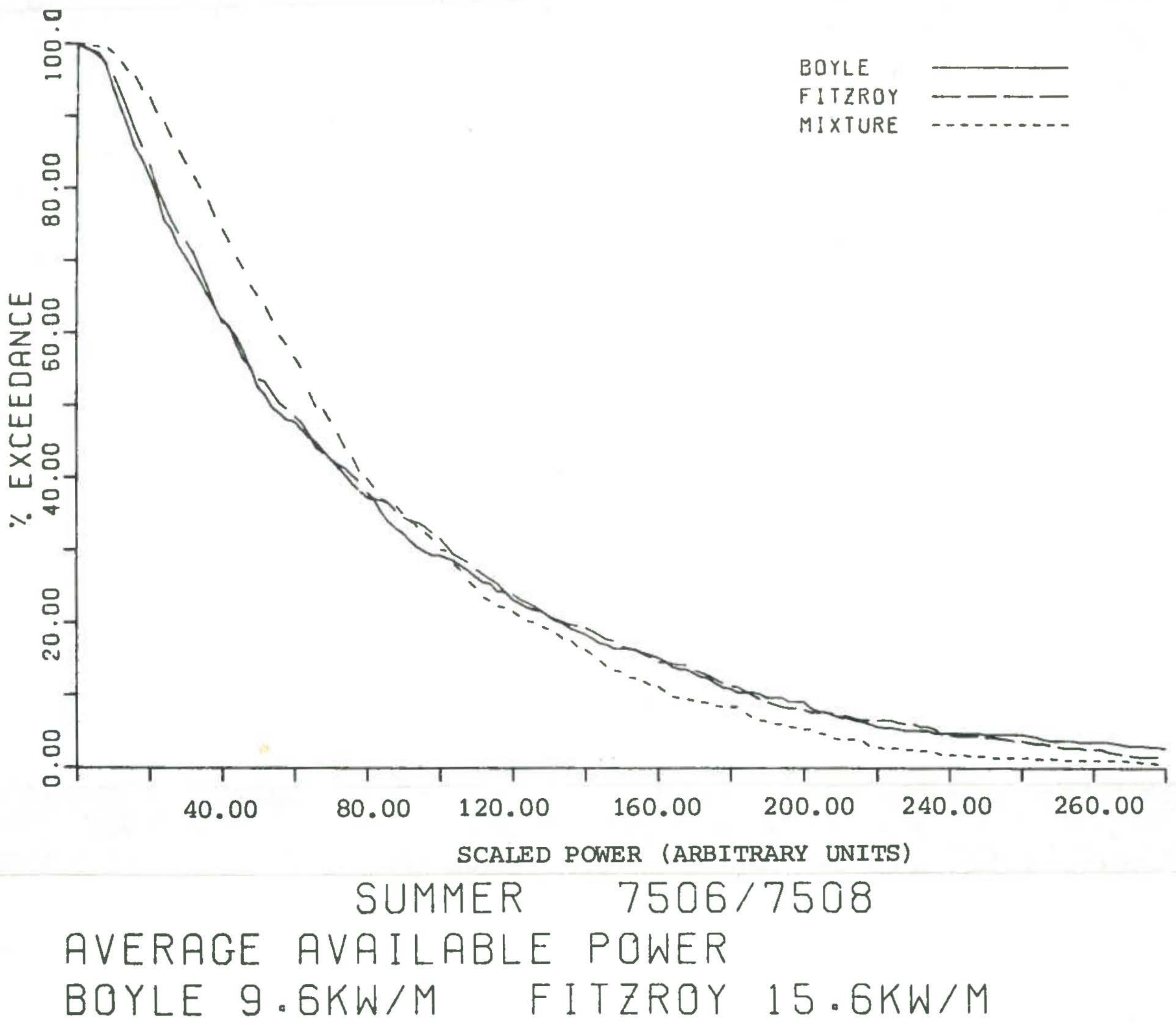


FIGURE 10

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
AVAILABLE POWER SUMMER 1975

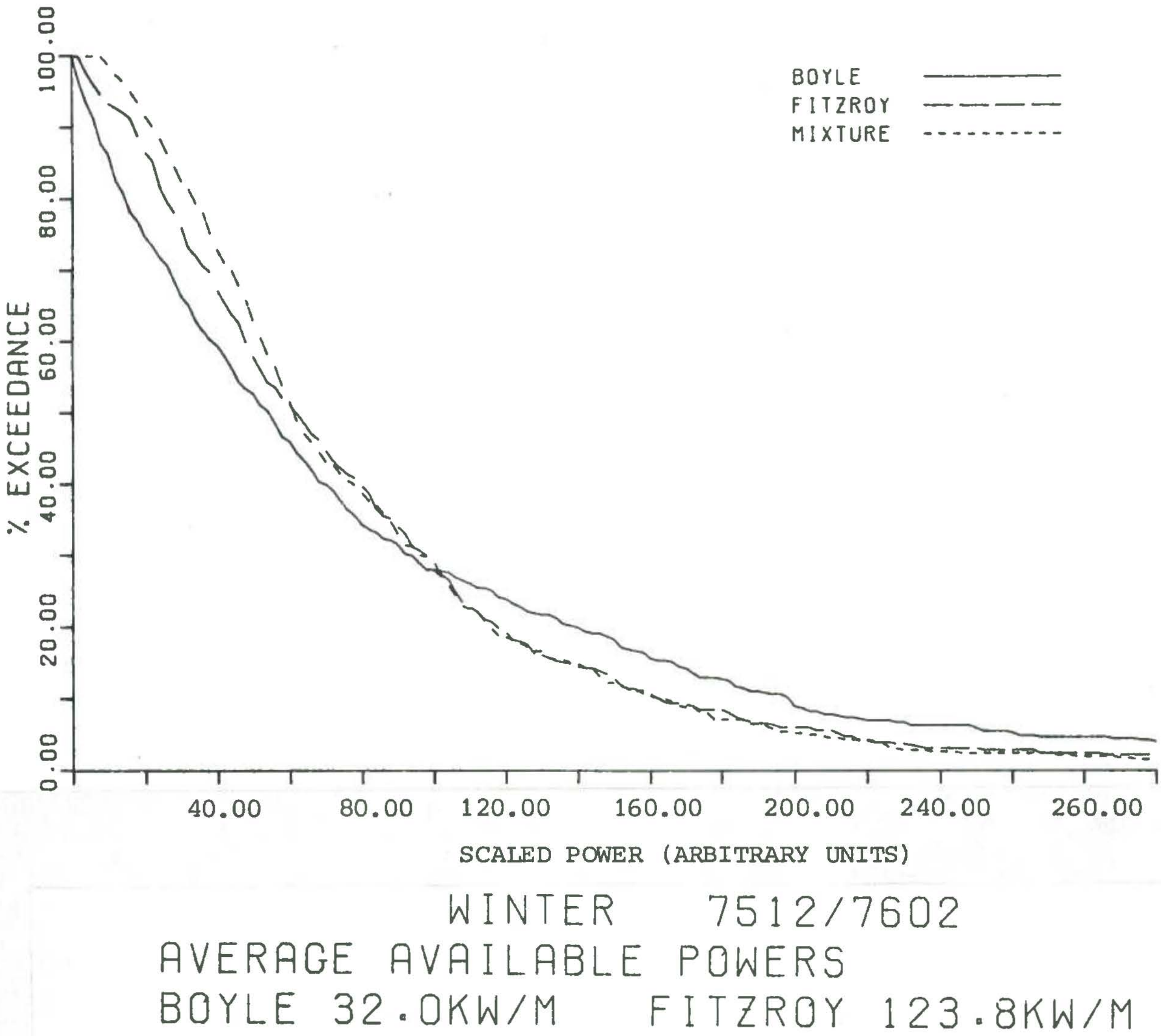


FIGURE 11

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
AVAILABLE POWER WINTER 1975/76

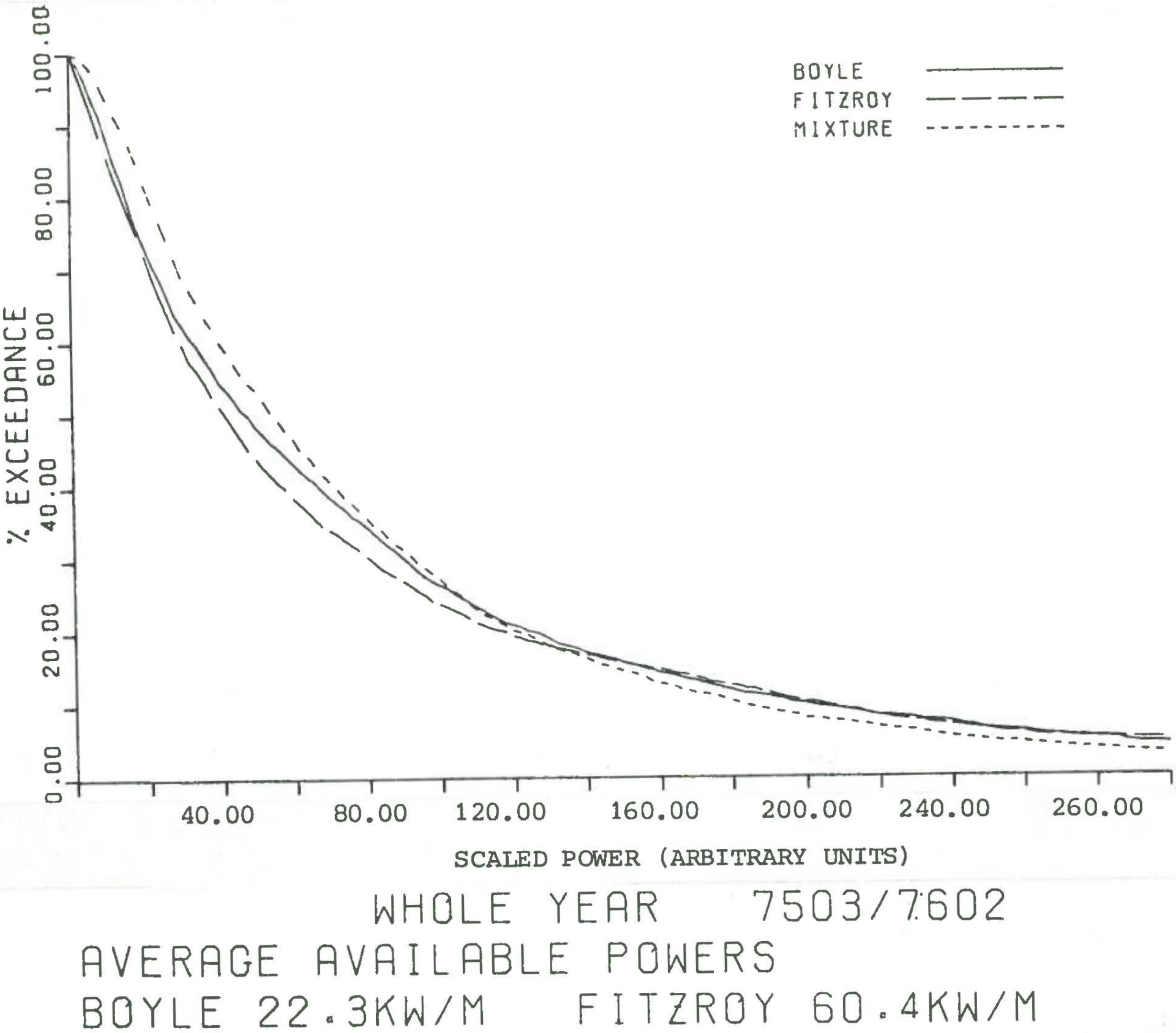
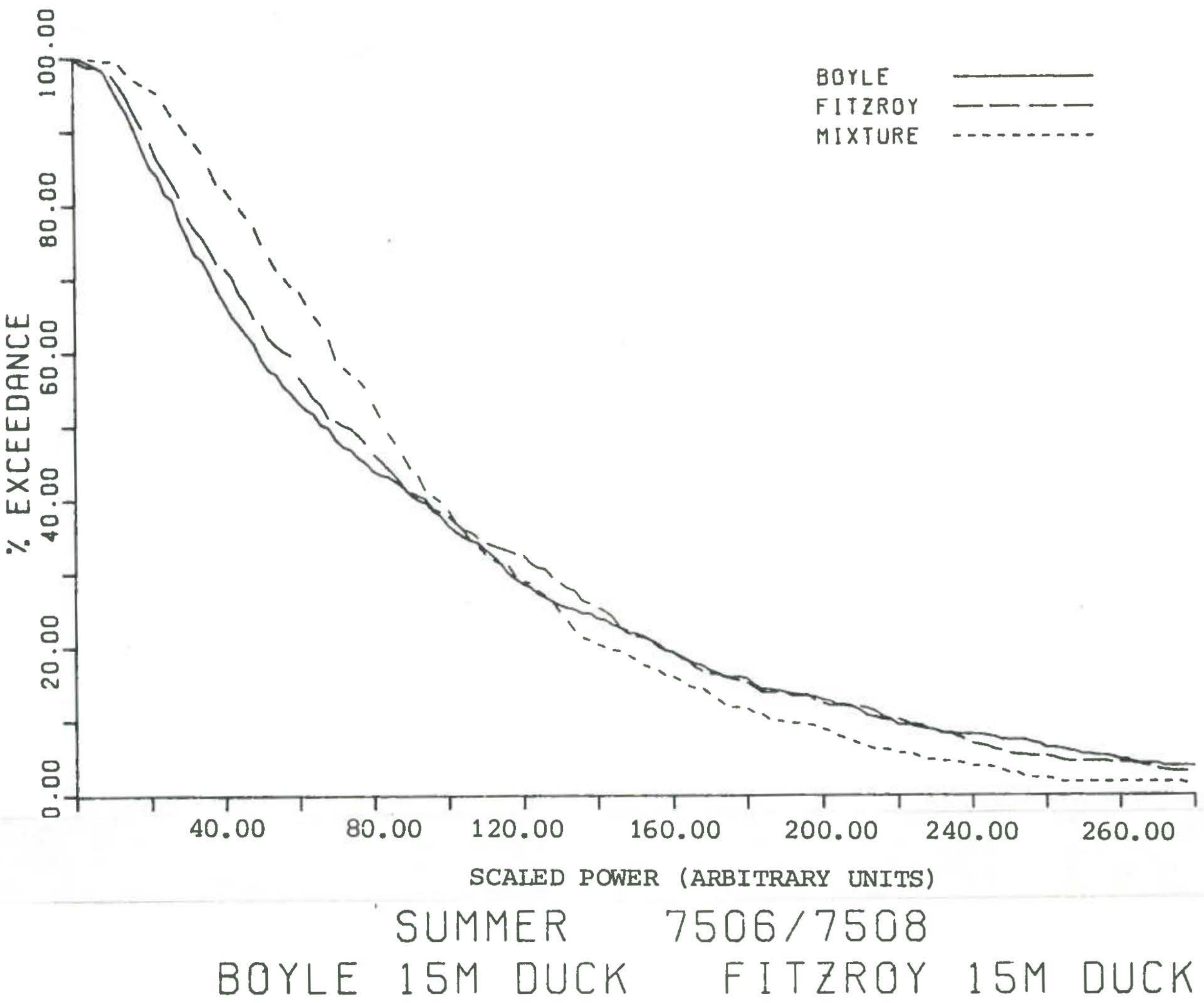


FIGURE 12

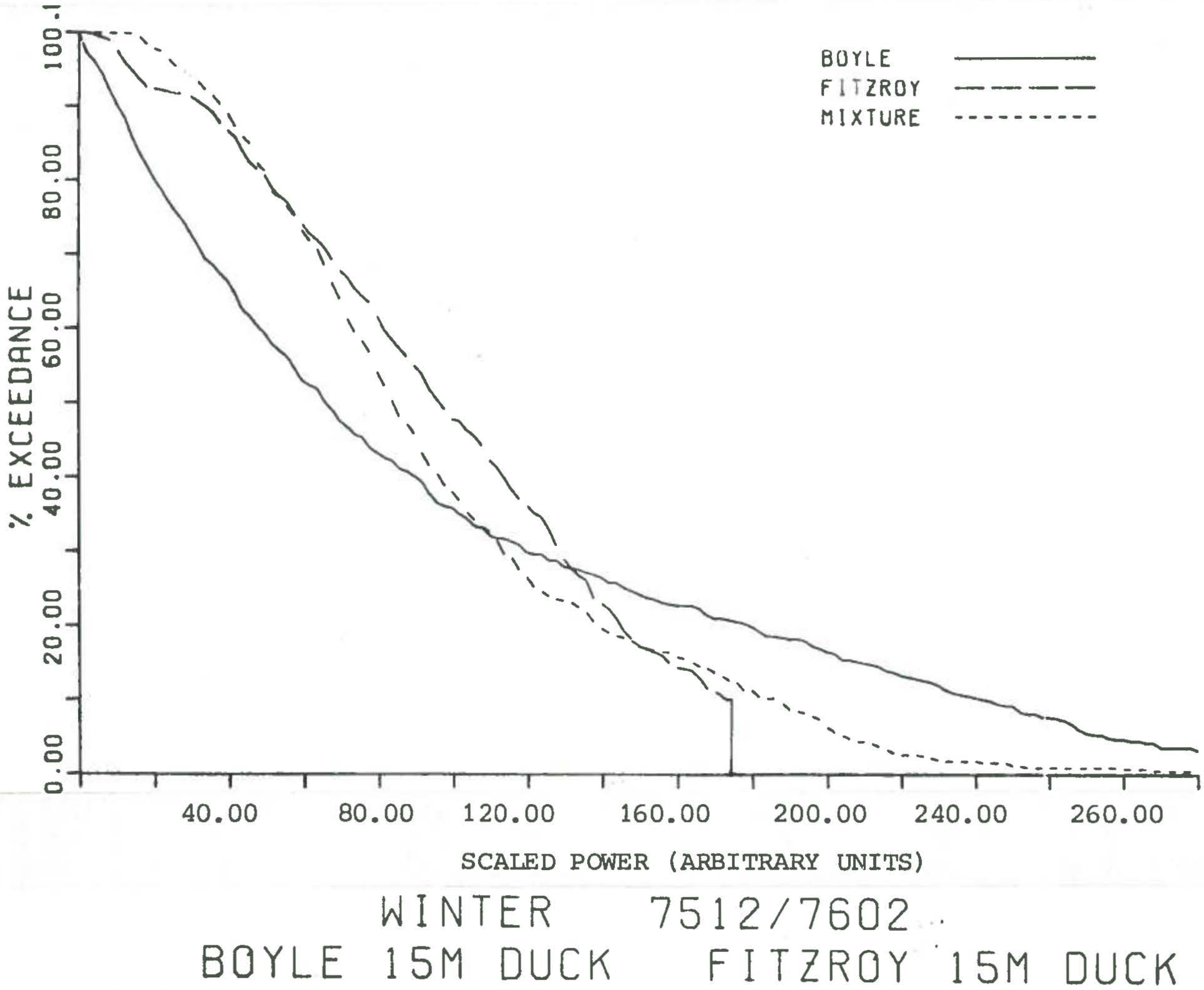
DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
AVAILABLE POWER WHOLE YEAR 1975/76



	BOYLE 15M DUCK	FITZROY 15M DUCK
TORQUE LIMIT MNM/M	1.00	1.00
POWER LIMIT KW/M	100	100
AVERAGE POWER OUT KW/M	7.6	12.2

FIGURE 13

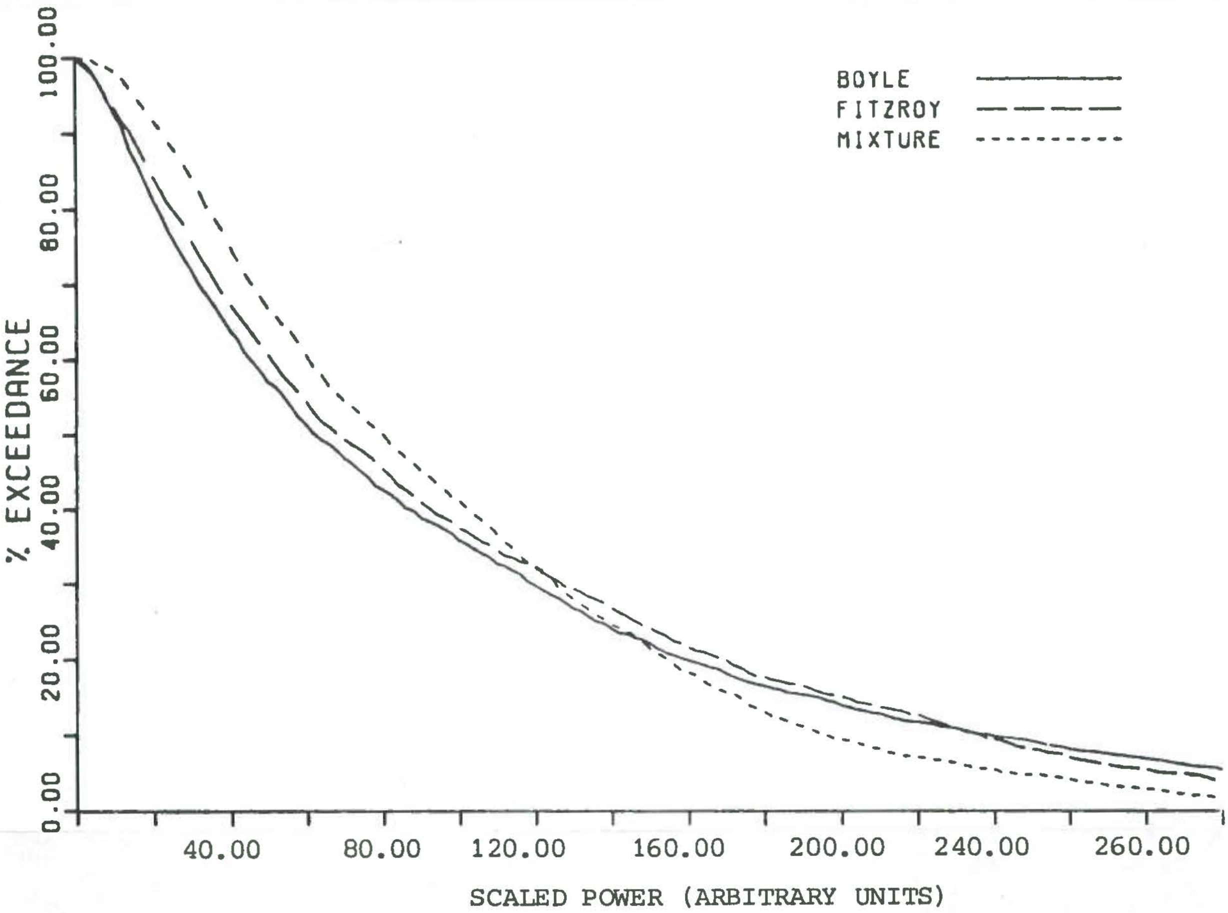
DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
ESTIMATED OUTPUT, SUMMER 1975 - 15 m DUCKS AT BOYLE & FITZROY



	BOYLE 15M DUCK	FITZROY 15M DUCK
TORQUE LIMIT MNM/M	1.00	1.00
POWER LIMIT KW/M	100	100
AVERAGE POWER OUT KW/M	19.4	57.2

FIGURE 14

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
ESTIMATED OUTPUT, WINTER 1975/76 - 15 m DUCKS AT BOYLE & FITZROY.

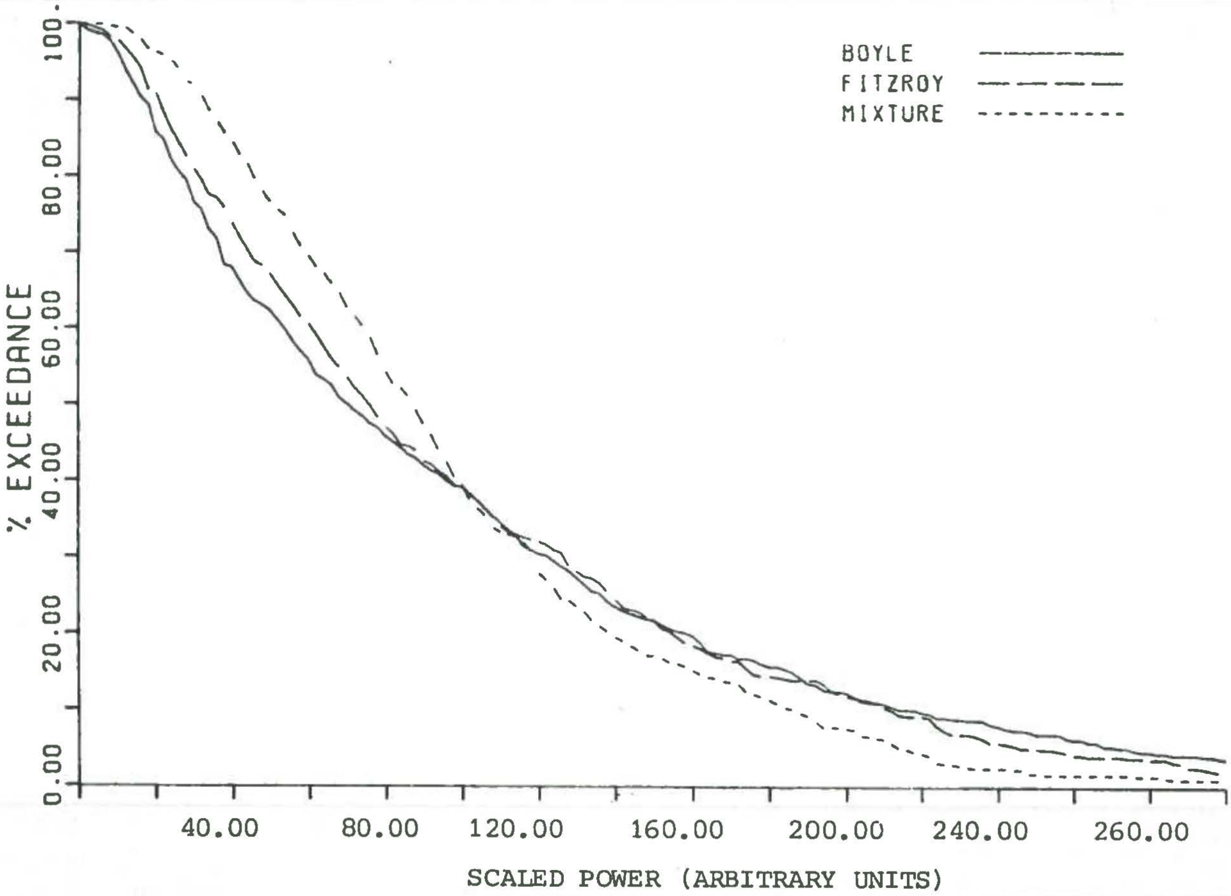


WHOLE YEAR 7503/7602

	BOYLE 15M DUCK	FITZROY 15M DUCK
TORQUE LIMIT MNM/M	1.00	1.00
POWER LIMIT KW/M	100	100
AVERAGE POWER OUT KW/M	15.2	32.3

FIGURE 15

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
ESTIMATED OUTPUT, WHOLE YEAR 1975/76 - 15 m DUCKS AT BOYLE & FITZROY.



SUMMER 7506/7508

BOYLE 10M DUCK FITZROY 10M DUCK

	BOYLE 10M DUCK	FITZROY 10M DUCK
TORQUE LIMIT MNM/M	0.26	0.54
POWER LIMIT KW/M	30	50
AVERAGE POWER OUT KW/M	6.2	9.8

FIGURE 16

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
ESTIMATED OUTPUT, SUMMER 1975 - 10 m DUCKS AT BOYLE & FITZROY

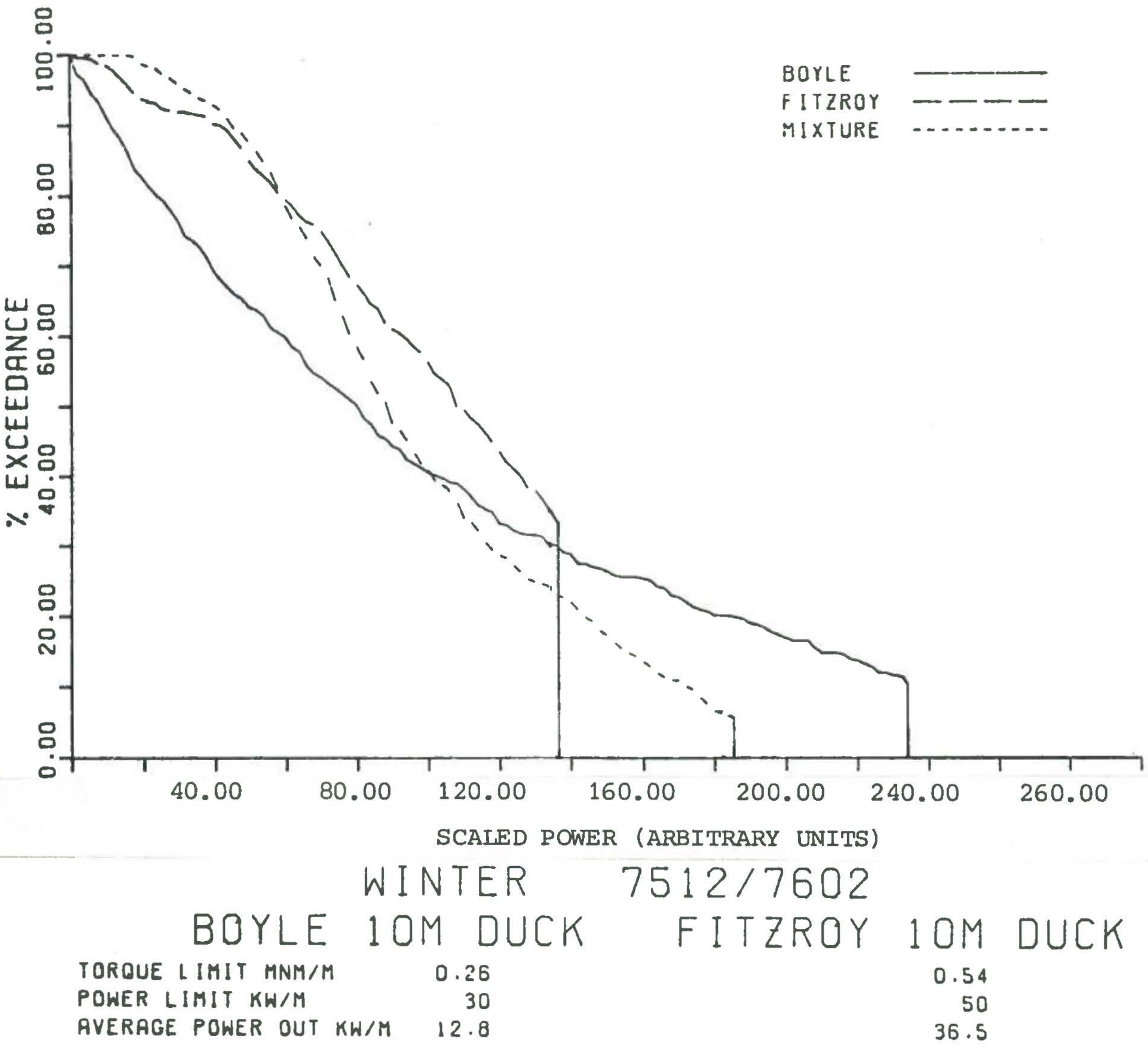
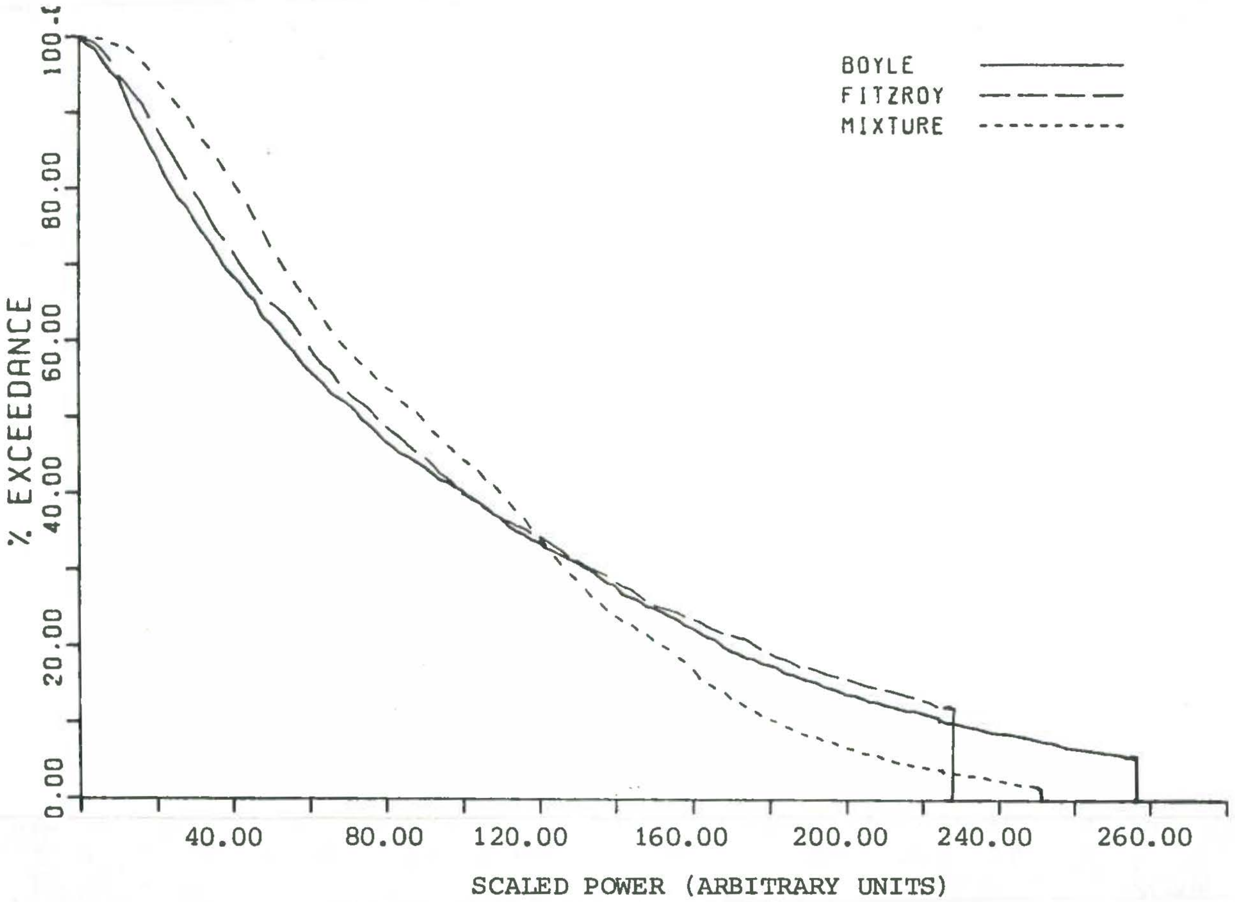


FIGURE 17

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
ESTIMATED OUTPUT, WINTER 1975/76 - 10 m DUCKS AT BOYLE & FITZROY



WHOLE YEAR 7503/7602

BOYLE 10M DUCK FITZROY 10M DUCK

	BOYLE 10M DUCK	FITZROY 10M DUCK
TORQUE LIMIT MNM/M	0.26	0.54
POWER LIMIT KW/M	30	50
AVERAGE POWER OUT KW/M	10.8	22.0

FIGURE 18

DISTRIBUTION OF POWER AVAILABLE FROM BOYLE AND FITZROY STATIONS SEPARATELY AND FROM A 1:1 MIXTURE OF THE TWO SITES.
EACH DISTRIBUTION IS SCALED TO HAVE AN AVERAGE OF 100 UNITS.
ESTIMATED OUTPUT, WHOLE YEAR 1975/76 - 10 m DUCKS AT BOYLE & FITZROY